Review of
Potential Impacts of the Proposed Rosemont Mine, southeast of Tucson, Arizona
on
Las Cienegas National Conservation Area (LCNCA) Hydrologic System

Friday, May 6, 2016

Prepared by
Robert H. Prucha, Phd, PE
Integrated Hydro Systems, LLC
Golden, Colorado

INTEGRATED HYDRO SYSTEMS, LLC

The Center for Biological Diversity (CBD) contacted Integrated Hydro Systems, LLC and requested Robert Prucha review available studies and evaluate assess potential impacts of the proposed Rosemont Mine, located southeast of Tucson on the Las Cienegas National Conservation Area to the east of the mine (see Figure 1). CBD indicated that both the Bureau of Land Management (BLM) and the Environmental Protection Agency (EPA) have both expressed concerns that the proposed Rosemont mine will capture groundwater which directly sustains surface water flows in the nearby Las Cienegas National Conservation Area (LCNCA) wetlands and Cienega Creek.

Specifically, CBD asked me to look at relevant hydrological studies to date and give them an opinion on whether:

(1) estimated hydrologic impacts of the proposed Rosemont Mine dewatering within LCNCA have been adequately assessed, and

(2) previous estimates of impacts on LCNCA waters can be improved?

1.0 Focus of Review

My review focuses on the evaluation of predicted future mining impacts on both the surface and subsurface hydrology within the Las Cienegas National Conservation Area (LCNCA) and also provides specific recommendations to fix and/or improve estimation of impacts. Because of the inherent uncertainty in these types of model-predicted future changes, my review also focuses on whether a complete and realistic range of potential impacts was determined, which sufficiently inform regulators who must then make critical decisions regarding permitting.

2.0 Organization of Review

For this review, reports I reviewed are summarized in Section 3.0, followed by key findings in Section 4.0, key recommendations in Section 5.0 and a summary of specific concerns in Section 6, categorized by standard model development steps.

3.0 Reports Reviewed

As part of my assessment, I downloaded and reviewed many reports prepared by Rosemont, their consultants and other stakeholders (http://www.rosemonteis.us/). I focused my review on the following reports by Montgomery and Associates (M&A), SRK and TetraTech. I refer to other studies included below in my review:

2015	Joe Gurrieri and Roger Congdon, USFS	Memo to Jim Upchurch, Supervisor, Coronado National Forest. Evaluation of Additional Groundwater Modelling Tasks Suggested by USGS for the Rosemont Mine Project.
2013	Jane Diamond, EPA	Memo to USACE Kim Colloton. Analysis of updated draft Clean Water Act #404 Compensatory Mitigation Proposals for Rosemont Mine, Pima County, Arizona.
2010	Montgomery and Associates Inc.	Revised Report: Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-closure, Vol. 1: Text and Tables. Prepared for Rosemont Copper. Tucson, Arizona: Montgomery and Associates Inc. August, 2010
2010	SRK	Technical Review of Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project. Prepared for SWCA and the Coronado National Forest. Technical Memorandum dated August 3, 2010.
2010a	TetraTech	Groundwater Flow Model Construction and Calibration. Prepared for Rosemont Copper Company. Technical Memorandum Dated July 26, 2010.
2010b	TetraTech	Regional Groundwater Flow Model. Prepared for Rosemont Copper Company. Report Dated November 26, 2010.
2010	Ye M, Pohlmann KF, Chapman JB, Pohll GM and Reeves DM.	'A model-averaging method for assessing groundwater conceptual model uncertainty', Groundwater 48(5):716–728
2010	Doherty, J.E., Hunt, R.J., and Tonkin, M.J.	Approaches to highly parameterized inversion: A guide to using PEST for model-parameter and predictive-uncertainty analysis: U.S. Geological Survey Scientific Investigations Report 2010–5211, 71 p.
2006	Jyrkama, M,I, and Sykes, J.F.	Sensitivity and uncertainty analysis of the recharge boundary condition, WATER RESOURCES RESEARCH, VOL. 42, W01404
2003	Neuman, S.P., and P.J. Wierenga.	A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites, NUREG/CR-6805. Washington, DC: U.S. Nuclear Regulatory Commission.

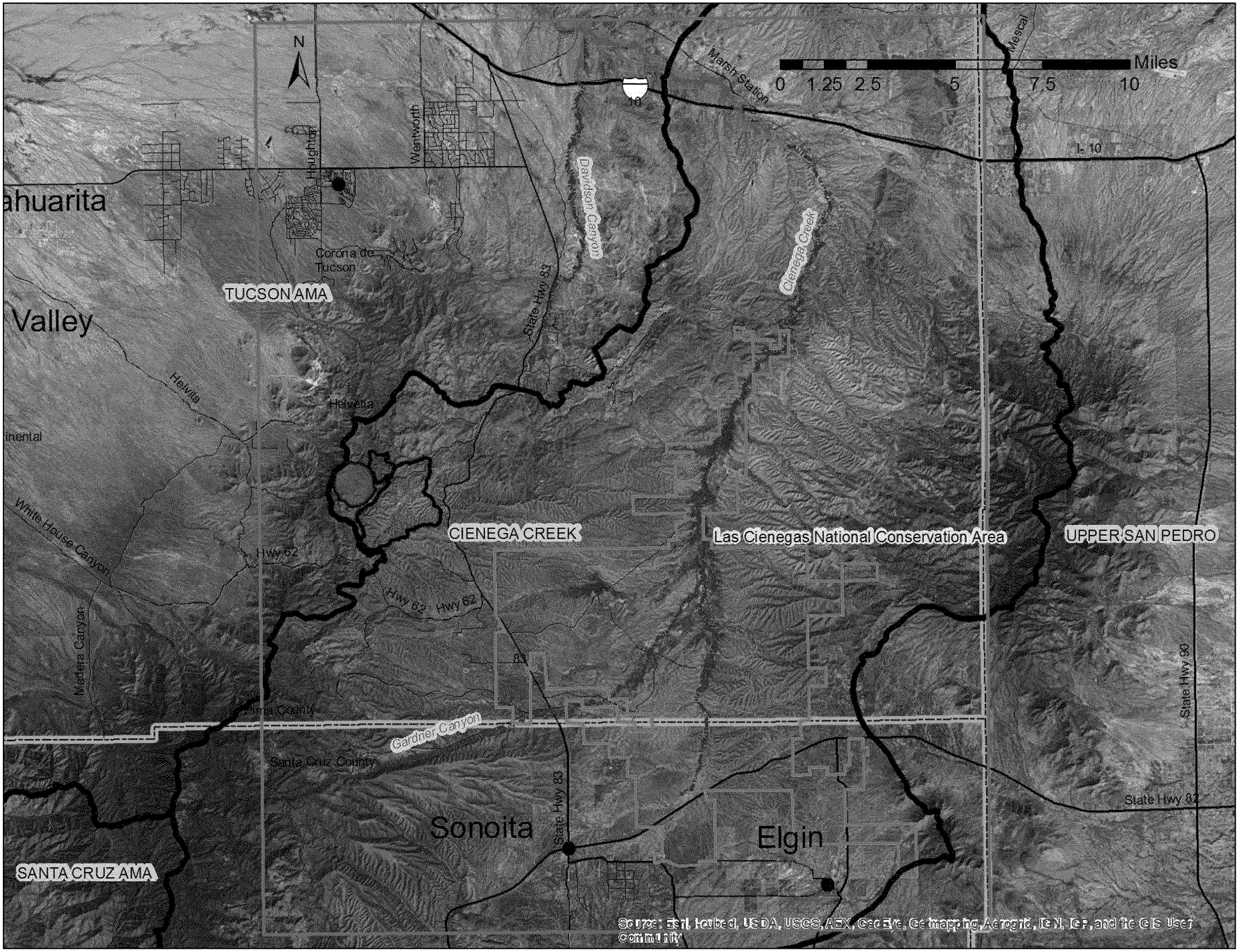


Figure 1. General Location of Las Cienegas National Conservation Area (LCNCA) relative to proposed Rosemont Mine (Red circle).

4.0 General Findings

Following my review, I found a number of issues with model development, including the overall methodology, characterization, conceptualization of flow, model setup/assumptions, calibration of the model and the selection process for selecting an appropriate software modeling tool to meet stated objectives. These issues alone reduce the overall credibility and accuracy of the modeling to such a level that it is difficult to trust major conclusions that the pumping will have only limited impacts on water resources within the LCNCA. Perhaps more importantly, given the high level of uncertainty with increasing distance from the mine, I found the sensitivity analysis, conducted instead of a more appropriate and rigorous industry standard uncertainty analysis, very limited due to the selective choice of which inputs to vary and by how much. In fact, I believe that had they conducted a more formal uncertainty analysis, which considers all sources of uncertainty and the significant model calibration error in the LCNCA, they would have found a much greater range of impacts to water resources within the LCNCA. I summarize the key findings by category below, and provide recommendations in Section 4.0.

1) **Overall Methodology**. Though the basic groundwater model of the regional system appears to have been setup similar to other mine dewatering models I've reviewed, reference to the methodology was never specified, and more importantly, it doesn't incorporate the very important step that evaluates whether additional data are needed to meet objectives. ASTM 5979-96 (2002). This standard "Standard Guide for Conceptualization and Characterization of Ground-Water Systems" shows a clear methodology for characterization and conceptualization of flows in surface and subsurface systems, which iteratively check at every step, whether data is adequate for objectives of modeling, which were to evaluate impacts of mine dewatering on surrounding water resources, including LCNCA.

   Limited data collection in LCNCA. This in turn limits necessary/adequate characterization of surface water hydrology and hydrogeology of the system, which in turn limits conceptualization of subsurface/surface flows and their interaction in the area. This in turn limits the ability to develop a defensible, realistic and credible numerical model of the hydrologic system, which can then reliably be used to estimate an appropriate range of impacts to both subsurface and surface hydrologic system within LCNCA. Data collection focused on the area near the mine.

   Though detailed industry standards exist and have been available for decades, and are widely cited, these do not appear to have been utilized in this modeling. Examples of key standards that should have been used include:

   a. D5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem

   b. D5490 Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information

   c. D5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling

   d. D5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling

   e. D5611 Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application

   f. D5718 Guide for Documenting a Ground-Water Flow Model Application

   g. D6025 Guide for Developing and Evaluating Groundwater Modeling Codes

2) **Characterization.** No baseline study of LCNCA to characterize, conceptualize and numerically model the flow system well enough to understand how it might be impacted by Rosemont operations. Even a basic understanding of arid/semi-arid zone stream-aquifer seasonal/annual dynamics within both

perennial and ephemeral reaches of the LCNCA network has not been established. Without understanding the fundamentals of how this complex system works, it is impossible to attempt to predict future 'regional-scale' response of this coupled hydrologic system, let alone attempting to simulate it's current 'regional' response without the mining.

3) **Conceptualization**. Though Rosemont consultants developed two different models, a realistic range of alternative conceptual models were not considered in the modeling that account for substantial uncertainty in virtually all model input (Figure 2 below shows examples of some alternatives that could have been considered and which would have had a notable impact on predictions). This only increases the non-uniqueness of the solution, which in turn produces high uncertainty in predictions that weren't considered in the parametric sensitivity simulations (which shouldn't be confused with uncertainty analysis). Neuman and Weiranga, 2003 describe in detail how to incorporate alternative conceptual models into formal uncertainty analyses. Typically, conceptual model uncertainty dominates overall predictive uncertainty and as such should have been more fully assessed.

4) **Model Setup/Assumptions**. I raise a number of issues with model setup/assumptions in the table below, which raises serious concerns about whether the model correctly simulates processes and implications for predictions of future mine dewatering on water resources within the LCNCA.

5) **Calibration.** Overall, I found calibration poor, especially in the LCNCA area and for hydrologic response:

    a. Calibration weighting of critical LCNCA hydrologic features (i.e., gage data, springs etc.) were weighted so low as to effectively eliminate reasonable calibration model performance in these areas. This is surprising, given that the stated objectives are to evaluate impacts of mining on key water resources in the area, specifically citing Cienega Creek.

    b. Calibration is shown to over- and under-shoot observation data by hundreds of feet. A discussion of how this significant error is translated into model prediction uncertainty within the LCNCA, or even why specific calibration target values weren't defined in the LCNCA to ensure the model was able to meet stated objectives were never presented.

    c. I created a spatial plot of simulated groundwater depths (see Figure 4), which I calculated in ArcGIS from a plot showing simulated groundwater levels from the calibrated model and available 10m topographic DEM data. Results appear to show significant areas in the vicinity of LCNCA with heads >10 to 100+ feet above ground surface. This by itself suggests calibration results within LCNCA area is not properly constrained, poor and highly unreliable. Groundwater levels should not be simulated above ground surface, except by a few feet beneath topographic drainages, unless data clearly show that high artesian pressures exist – which by itself would also require the modelers to also revisit the conceptual flow model (which doesn't show this).

6) **Model Code Selection**. The modeling tool used by Rosemont consultants to assess mining impacts on important surface water features within the LCNCA, don't meet stated objectives of the modeling studies because of grid scale issues (i.e., computational limitations don't permit selected code to model water resource features accurately). The selected modeling code also fails to model important physical processes (i.e., surface runoff processes, recharge dynamics, stream hydrodynamics, and stream-aquifer dynamics etc.) that would allow simulating realistic/reliable impact of mine dewatering on LCNCA water resources. Better tools actually exist, but they failed to conduct an industry standard code selection process, where they could have easily identified key modeling code needs to meet objectives, then selected a more appropriate code:

a. The variable saturation, finite element modeling code, Feflow, developed by DHI-WASY would have allowed a much higher resolution near critical streams, while decreasing resolution in area of less interest. This would have met stated objectives.

b. Fully integrated, or coupled, physically-based, fully-distributed hydrologic (and hydraulic) codes have been available for decades and would have allowed authors to better simulate the complicated coupled dynamics of the surface water-groundwater system within LCNCA. The authors attempted to estimate spatial distributions of recharge, which is a complex spatially distributed, and dynamic process, using an undocumented method. However, fully integrated codes like the USGS GSFLOW code, DHI's code MIKESHE/MIKE11 (which I've used extensively to calculate distributed recharge) or even Aquanty's Hydrogeosphere code actually simulate important processes like surface runoff and channelized hydrodynamics, which are dynamically coupled to subsurface flow (i.e., coupled to a mudflow equivalent code).

c. If Rosemont consultants still insist on using a groundwater-only code (i.e., Modflow) to estimate impacts within the LCNCA, modelers should at least use more current and appropriate versions of the software which would simulate ET and Recharge processes more realistically:

    i. ET boundary condition – Instead of using the original MODFLOW EVT package which treats ET loss as a linear function of hydraulic head (not very physically realistic), consider using MODFLOW Riparian ET package (available for MODFLOW-2005) http://pubs.usgs.gov/tm/tm6a39/pdf/tm6a39.pdf, or even the ETS package (http://pubs.er.usgs.gov/publication/ofr00466).

    ii. Recharge boundary condition – See the following publication on the Basin Characterization Method (BCM) currently used by the USGS in a number of southwestern basins. (http://pubs.usgs.gov/pp/pp1703/b/pp1703b.pdf) or (http://pubs.usgs.gov/sir/2007/5099/).

7) **Sensitivity and Uncertainty Analyses**. The predictive sensitivity analysis conducted by the Rosemont modelers did not consider all of the factors that could have 'conservatively' increased the range of potential impacts within the LCNCA. Figure 3 summarizes key factors I believe should have been considered individually and collectively to assess a more realistic conservatively high range of impacts in the LCNCA. It remains unclear why the modelers wouldn't have also evaluated different combinations of adjustments to 'sensitive' parameter values, or different configurations of spatially distributed parameters (versus just adjusting all values up or down some arbitrary amount). Adjustments to combinations of sensitive parameters could easily produce much greater impacts in the LCNCA than adjustments to just individual parameter values.

   I also believe that the modelers may have confused a predictive sensitivity analysis with a predictive uncertainty analysis. The distinction is very important, as a sensitivity analysis does not provide a true assessment of model uncertainty (see Neuman and Weiranga, 2003, Doherty et al, 2010) – typically perturbations cause the model to fall out of calibration, which make the results unreliable. Yet the authors use the range of output from simulations using arbitrary adjustment of selective (i.e., cherry picked) parameters, to imply they've considered the full range of possible impacts at LCNCA. A predictive uncertainty analysis, would provide much more industry standard estimates of prediction uncertainty, at least considering parameter uncertainty. The authors didn't evaluate realistic alternative conceptual models; uncertainty in conceptual models typically causes the majority of predictive uncertainty.

   Ultimately, model predictions of impacts on water resources within the LCNCA are considered highly uncertain, due to a combination of the high level of input uncertainty, high conceptual model uncertainty, uncertainty in calibration data, and notable model error. While it appears that the modelers, and subsequent reviewers, have all acknowledged results are uncertain, especially with increasing distance from the mine operations, further evaluation of uncertainty appears to have been dismissed in favour of highly selective sensitivity evaluations (Gurrieri and Congdon, 2015). Conducting a greatly simplified/selective sensitivity evaluation and then implying it provides a complete understanding of model uncertainty is highly misleading and misses the understated value of conducting a much more rigorous uncertainty analysis, especially related to impacts to the LCNCA hydrologic system. An uncertainty analysis attempts to define a range of equally plausible predictions, all of which meet specified calibration constraints/targets, by adjusting individual/combinations of model inputs, to which the solution is most sensitive. Results of a sensitivity analysis may provide a sense of model inputs that model predictions are most sensitive, but they do not bracket the full range of equally possible solutions that meet objective function constraints (i.e., minimizing the difference between historical and simulated heads), and as such should not be used in lieu of a more robust constrained uncertainty analysis. Conducting a formal uncertainty analysis as suggested by the USGS Monte Carlo (Gurrieri and Congdon, 2015) and implied by EPA risk-based approach (Diamond, 2013) would provide a much better sense of the full range of potential impacts within the LCNCA, which should then be used to better inform critical decisions related to mine permitting.

Gurrieri and Congdon, 2015 state "The bottom line is that the method used in the Rosemont modeling; Sensitivity Analysis, is a rigorous and acceptable technique for evaluating uncertainty. There does not appear to be anything gained by performing further uncertainty analyses, including the Monte Carlo method. A Monte Carlo analysis is not a trivial task and the results probably would not change the overall conclusions that have already been established."

The null space Monte Carlo Constrained Maximization/Minimization method (Doherty et al, 2010) can provide the very important result of conveying the range (maximum – minimum) of equally plausible predictions of impacts at LCNCA. The current sensitivity analysis is a) too selective – doesn't consider combinations of sensitive parameters and b) isn't constrained to minimize objective function (i.e., reproducing historical conditions within some value).

The well known parameter estimation code PEST can be used in conjunction with existing calibrated groundwater models to determine a full range of uncertainty in predicted effects on water resource within the LCNCA using the Null-Space Monte Carlo method (see Doherty et al, 2010). The choice of the target or threshold objective function level at which the model is deemed to be "calibrated" is often subjective (Though targets should be determined based on required accuracy in LCNCA areas of interest following, for example a baseline study of this flow system that defines minimum environmental flows or changes to the hydrologic/ecologic system, to avoid irreverisble damage).

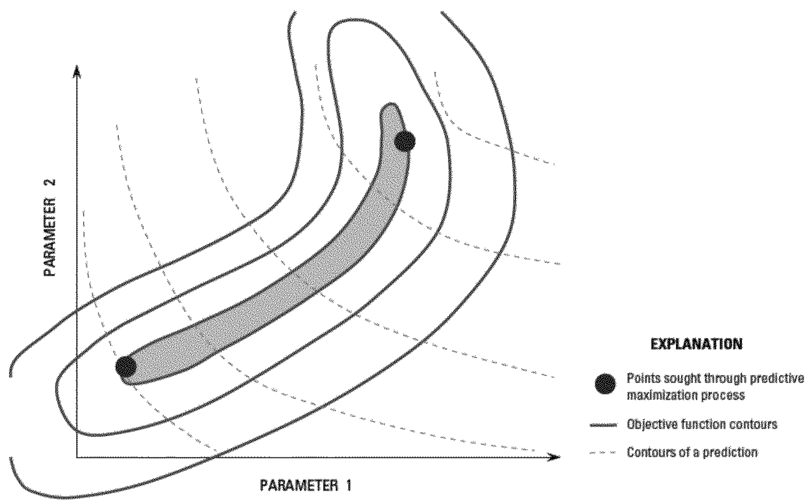


Figure 6. Schematic description of calibration-constrained predictive maximization/minimization.

Doherty et al, 2010 states "The principle that underlies this methodology is illustrated in figure 6 (below) for a two-parameter system. In this figure, the shaded contour depicts a region of optimized parameters that correspond to the minimum of the objective function. The solid lines depict objective function contours; the value of

ED_001040_00003502-00008

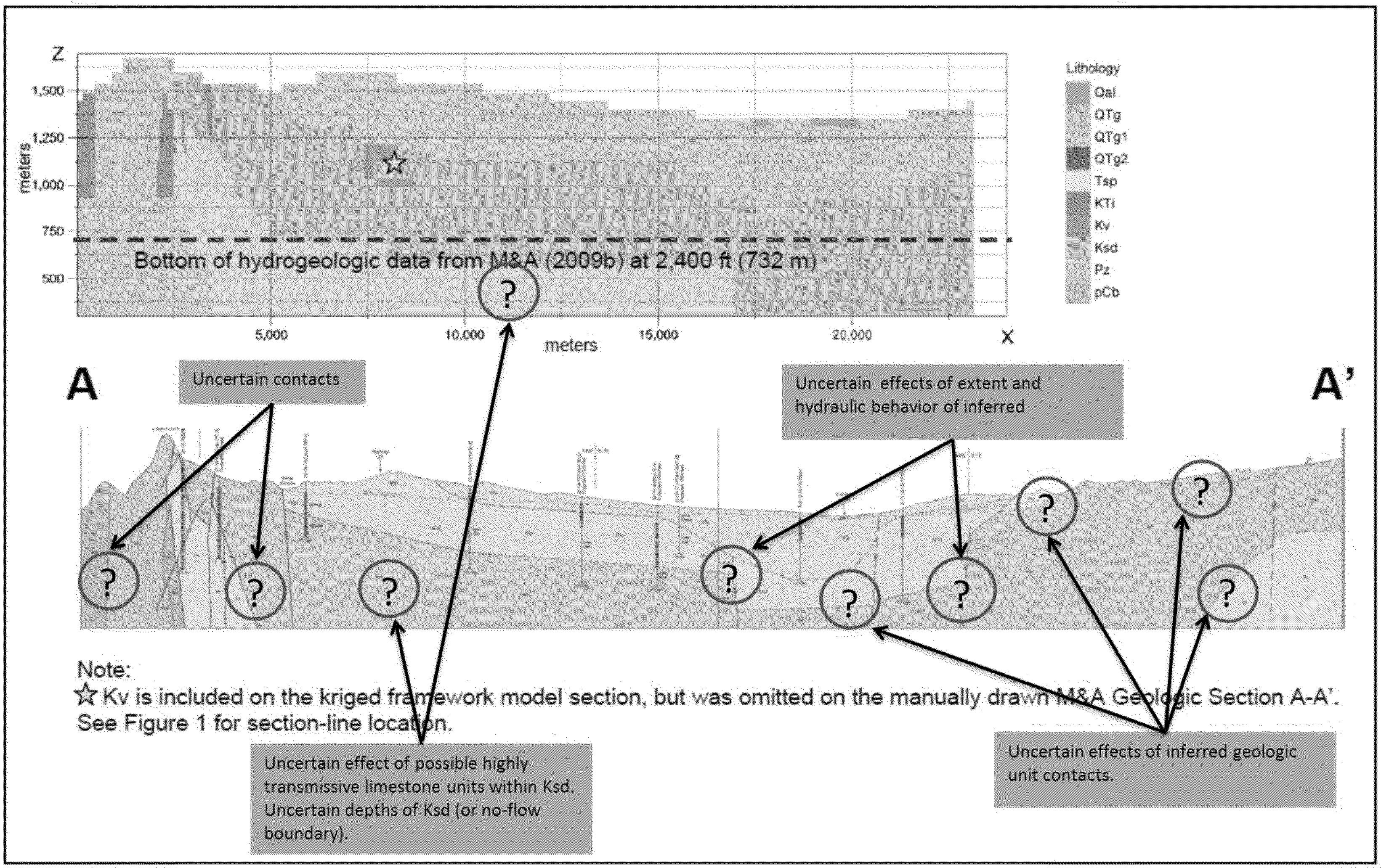
each contour defines the objective function for which parameters become unlikely at a certain confidence level. Each contour thus defines the constraint to which parameters are subject as a prediction of interest is maximized or minimized in order to define its postcalibration variability at the same level of confidence. The dashed contour lines depict the dependence of a prediction on the two parameters. The constrained maximization/minimization process through which the postcalibration uncertainty of this prediction is explored attempts to find the two points marked by circles on the constraining objective function contour. These points define parameter sets for which the prediction of interest is as high or as low as it can be, while maintaining respect for the constraints imposed by the calibration process."

5.0 Key Recommendations

1) Based on my review, I would strongly recommend that more appropriate modeling tools be used to meet objectives of the modeling. These would need to be re-calibrated to more appropriate data, collected in areas, depths and temporal frequencies required to simulate realistic coupled stream-aquifer flow conditions within the LCNCA.

2) Uncertainty will always be present in model predictions, but at a minimum, decision makers should require Rosemont to fully assess predictive uncertainty, such as outlined in the null space Montel Carlo method (Doherty et al, 2010) using the industry standard parameter estimation code PEST. One reason to consider such an uncertainty analysis is that if a permit is issued, based on a monitoring approach, no amount of mitigation could be performed to reverse likely significant damage to the LCNCA water resources and associated ecosystem because groundwater storage beneath a broad geographic area beneath and surrounding the mine will already be developed, over many decades. After mine closure, it would be difficult to find funding or technology that somehow mitigated the pit lake evaporation sustaining the perpetual groundwater sink.

   In addition to assessing predictive uncertainty, steps should also be taken to reduce predictive uncertainty in areas like LCNCA, by fixing the model inputs, using more robust tools that better simulate stream-aquifer flow conditions, and improve calibration of the model to critical water resource features like springs and creeks in Cienega Creek Groundwater Basin (which were assigned very low calibration weights – effectively removing them from calibration). These are the critical water resource features that the groundwater model was supposed to simulate to evaluate impacts of mine dewatering.



Project No: 114-320874

July 2010

Figure 5
Comparison of Geologic Section A - A'
with Flow Model Geologic Block

Figure 2. Many alternative conceptual models could have been considered, just based on uncertainties in available structural geologic information as indicated here at red circles.

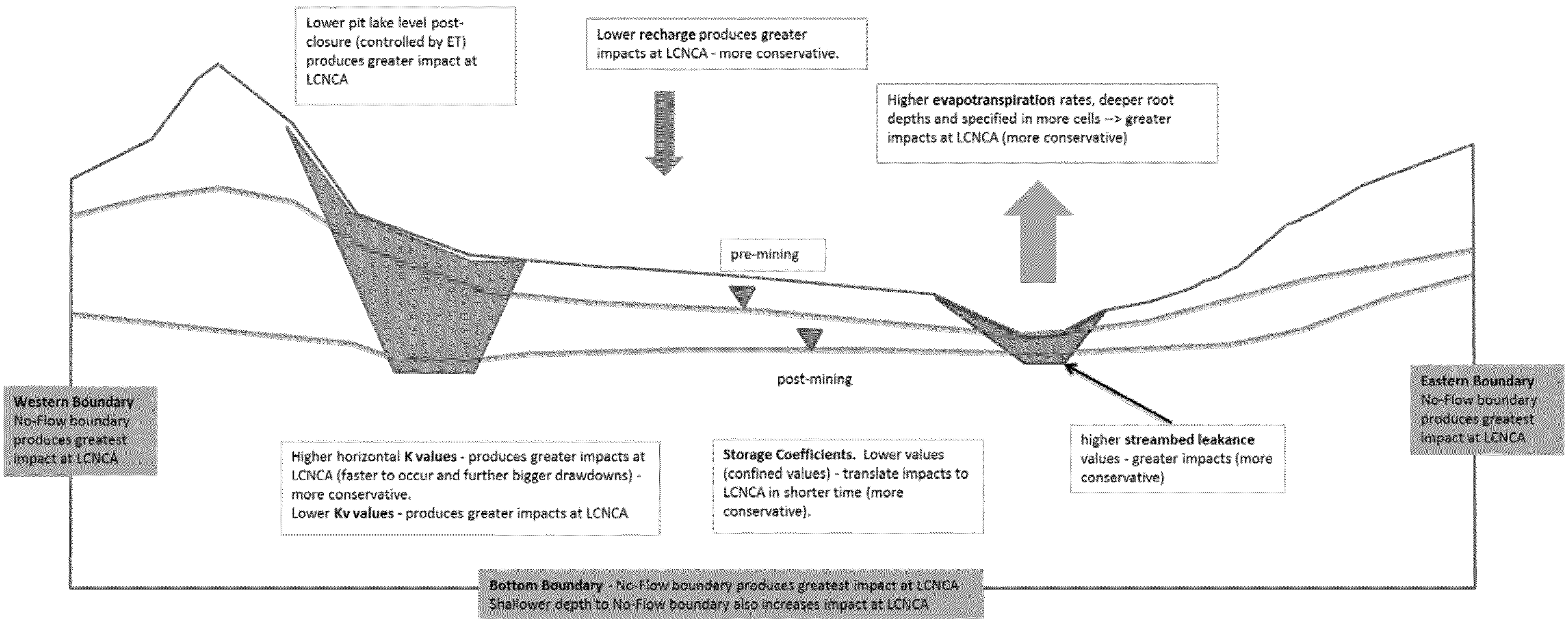


Figure 3. Key factors to consider in estimating 'conservatively' high impacts, and the adjustment direction to increase impacts at LCNCA. The combination of conservative values for each of these factors that would likely produce the high end of impacts at LCNCA and should be determined within the bounds of a properly calibrated model (or set of calibrated models based on alternative conceptualizations).

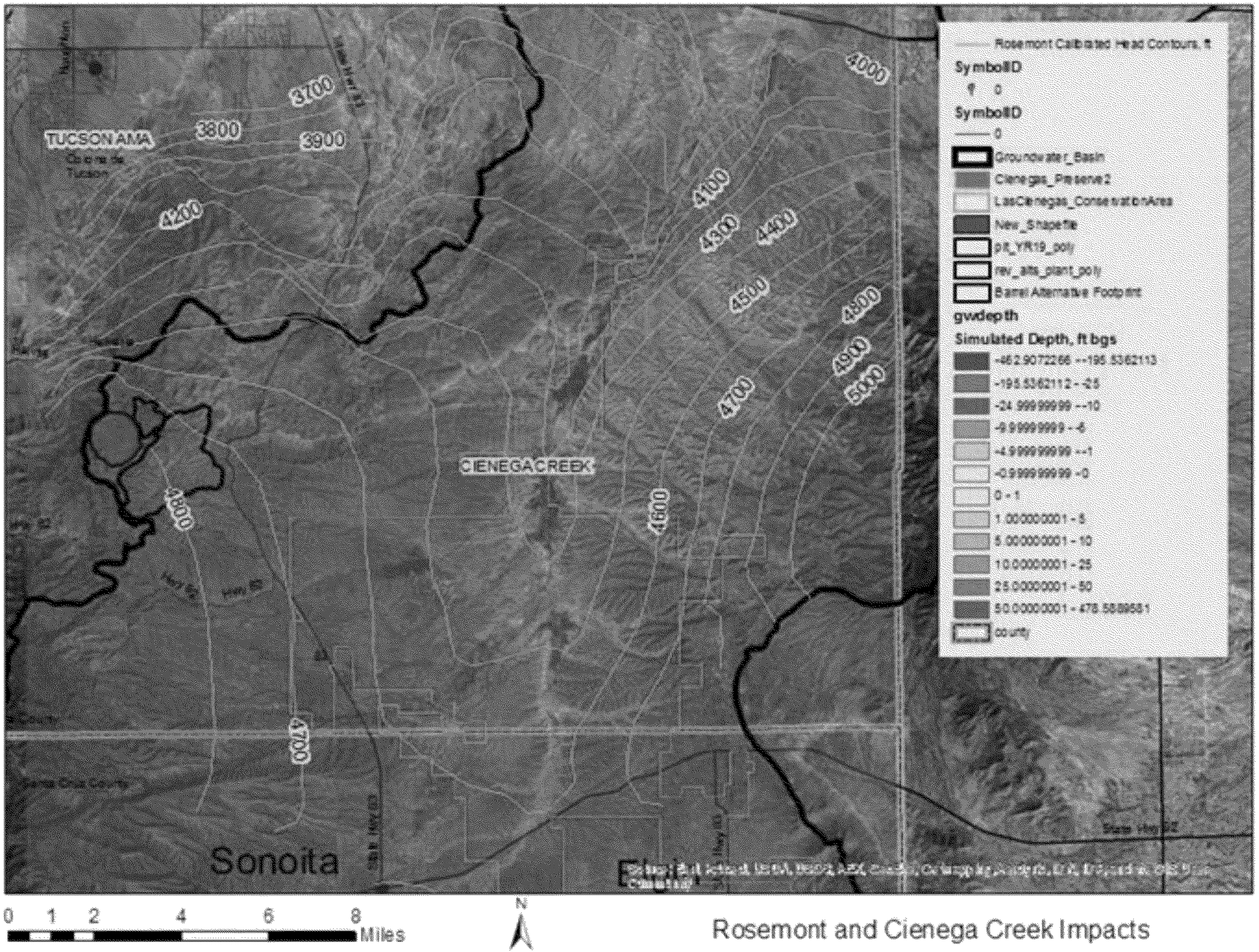


Figure 4. Plot shows approximate calibrated groundwater depths, which I calculated by subtracting a gridded raster created from simulated groundwater contours shown (cyan lines) digitized from Figure 39 in Tetra Tech 2010a from a 10 m topographic DEM surface obtained online from a USDA gateway source. Blue shaded areas indicate where the calibrated model simulates groundwater levels 10 to >100+ feet above ground surface. Except in perennial reaches, this represents a significant error.

6.0 Specific Comments

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
1	Data		Tetra Tech, 2010a	Evaluation of data adequacy for modeling of LCNCA (i.e., data gaps and data quality/quantity) seems to have been an oversight.	NO effort appears to have been made to define minimum data needs and modeling types/resolution/accuracyin LCNCA to determine all impacts. In other words, LCNCA should have been baselined, to form basis for required accuracy/dynamicsetc. - which would have required a) collecting right data, distribution, density, frequency etc., and b) using right tools.	More detail should have been stated in objectives of evaluating mining impacts on LCNCA. This drives all subsequent modeling/data collection etc.
2	Characterizations		Tetra Tech, 2010a	NO strategy for determining data adequacy. If a standard approach/methodology had been adopted for the modeling efforts, a key part of the efforts should have involved determining whether data were adequate to meet objectives (i.e., part of which were to assess mining impacts in LCNCA). This is standard practice - see (ASTM D5979 – 96 (2002) Standard Guide for Conceptualization and Characterization of Ground-Water Systems). This is an iterative process with data collection, characterization and conceptualization, where data gaps are identified and filled so that modeling is based on more reliable conceptualizations of flow.	It is clear that data are sparse throughout the model, but especially outside the mining area, and even more so, within the LCNCA. Though typical of mining projects, where funds are spent understanding near-mine conditions, the high profile of this project and stated modeling objectives to estimate impacts on mine dewatering on key water resources within LCNCA, should have required careful evaluation of data adequacy to meet objectives, and where significant data gaps exist - they should have been filled.	A key data gap that should have been filled in the LCNCA should have been obtaining better distributions of groundwater level time series over multiple years, where measurements are collected at least monthly, or at least daily time-series of surface discharge along both perennial and ephemeral reaches of streams within LCNCA (i.e., Cienega Creek and Gardner, among other smaller tributaries). Studies should have been conducted to baseline hydrology/hydrogeology within LCNCA so that more appropriate changes could be predicted due to mine dewatering, despite being 8 to 10 miles away. The dewatering is substantial and will be around into perpetuity.
3	Characterizations	Characterization of LCNCA surface water-groundwater interaction.		No effort seems to have been made to characterize surface water-groundwater interaction in LCNCA using standard methods.	The implication is that conceptualization of flows within LCNCA is poorly known/understood, especially seasonal flow dynamics of where and how much groundwater discharges into ephemeral/perennial streams like Cienegas Creek and its tributaries, or where surface flow leaks back into the underlying aquifer.	A baseline study should be conducted on the hydrogeology and hydrology within the LCNCA, with appropriate data (i.e., at least monthly monitoring of groundwater levels in shallow wells or piezometers beneath multiple reaches of drainages, in which stream stage at the same times is also monitored) so that the hydrology of the system can be first understood, then modeled and then evaluated for more likely impacts due to proposed Rosemont dewatering. Consider using stream/groundwater temperature data to determine critical streambed leakance values that control flows between the stream and aquifer. Defining streambed leakance values based on field data would permit the model to better simulate changes in baseflow discharge.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
4	Conceptualizations		Tetra Tech, 2010a and 2010b	Alternative conceptual models weren't really considered, other than M&A and TT models, which relied upon the same geologic model. This is a major concern as conceptual model uncertainty typically produces much greater uncertainty than does uncertainty in parameters (see Ye et al, 2010, and page 6 and 7 of Neuman, S. P. and Weirenga, P. J.. 2003. A comprehensive strategy of hydrogeologic modelling and uncertainty analysis for nuclear facilities and sites, NUREG/CR-6805). Conceptual models need to be developed prior to modeling and are used as basis build subsequent models. High uncertainty in subsurface configuration, parameter distributions etc. --> require multiple conceptualizations until one can dismiss with confidence.	The implication is that conceptualization of current flows within LCNCA remains poorly known/understood, especially seasonal flow dynamics of where and how much groundwater discharges into ephemeral/perennial streams like Cienegas Creek and its tributaries, or where surface flow leaks back into the underlying aquifer. This becomes even more important when the entire aquifer system is stressed by mine dewatering into conditions well outside of the largely natural state it is in currently. As such, errors introduced by conceptual uncertainty into the calibrated model will translate into prediction uncertainty. Results of current model predictions are uncertain - and the range of potential impacts is unrealistic (i.e., not very conservative).	Given the non-unique solution obtained during calibration (i.e., inverse problem with highly correlated recharge and hydraulic conductivity parameters and calibration to effectively just water levels in wells), develop more alternative conceptual models - see Figure 1 for examples of possible alternatives just in subsurface (i.e., different configurations of geologic units, faults etc.). Other alternatives should be considered when adding stream-aquifer flows (i.e., streambed thickness, hydraulic property distributions etc.) and ET.
5	Modeling Objectives		Tetra Tech, 2010a and 2010b	Tetra Tech, 2010a page 1, Section 1.1 states "The objective of the groundwater flow modeling is to provide estimates of impacts to area water resources. Potential impacts to Cienega Creek, Davidson Canyon, and regional spring flows are of particular interest." In the same Section, page 2 it states "Simulation of a regional area limits the resolution of the finite-difference model grid cells, which limits the resolution and accuracy of the model simulations. Hydrogeologic features smaller than the grid resolution are typically not simulated, and geometries and distributions are approximate. Small magnitude flows, small water-level changes, and steep hydraulic gradients are therefore difficult for a regional model to replicate." The concern is that the second statement effectively says the objectives can't be met. It is unclear why authors would state clear objectives, then say they aren't achievable in the same section. This appears to be a major flaw in the analysis, given the wide industry use and acceptance of alternative numerical methods.	The implication is that by design, the modeling would not meet stated objectives, or to estimate impacts of mine dewatering on water resources within LCNCA given limitations in the methods employed. The second statement presumes that only the finite difference Modflow (surfact) code could be used.	The authors fail to note that many other numerical modeling codes are available that could achieve stated objectives. See the comment below under Model Code Selection for further recommendations. Clearly stated objectives should be presented, followed by a clearly defined **achievable** approach and methods, which are accepted by industry (i.e., ASTM standards).

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
6	Modeling Methodology	Overall Approach/Methodology	Tetra Tech, 2010	Flow chart of modeling steps missing. Where is standard approach and methodology? ASTM standards present this - Refsgaard presents this - Anderson/Woessner present this. Data collection --> characterization --> conceptualization --> modeling --> calibration --> sensitivity (key parameters/errors) --> predictions --> predictive sensitivity --> uncertainty analysis. Present qualified range!! Key Concern --> missing part where data gaps are identified and new data collected, after initial conceptualization (iterative loop).	Without a clear approach/methodology, the entire approach here is confusing and probably one key reason why no range of predictions, given obvious uncertainties, were presented NOR, perhaps more importantly, why no effort was made to identify critical gaps (causing high uncertainty), data collection, model updates etc. etc.	Go back and update model with more robust inputs and utilize more robust tools/gridding techniques so that critical features of interest in objectives (i.e., Cienega Creek and springs) can be modeled more appropriately. See http://www.astm.org/Standards/D6170.htm for appropriate standards to select an appropriate code. http://www.epa.gov/sites/production/files/2015-05/documents/402-r-94-012.pdf. See Anderson and Woessner 2015, "Applied Groundwater Modeling: Simulation of Flow and Advective Transport"
7	Modeling Methodology	Modeling Standards		Industry standards are mentioned in many of the Rosemont reports, but details are never provided. The primary concern here is that industry standards such as ASTM don't seem to be utilized to guide the various steps of modeling. Examples of concern include: 1) effectively no code selection was performed - yet this has been and continues to be an important step in developing suitable models to meet stated objectives (see ASTM D6170 - 97(2010) Standard Guide for Selecting a Groundwater Modeling Code). 2) characterization/conceptualization never resulted in assessing data adequacy or collecting new data to meet objectives of modeling - instead only sparse available data were used to build/calibrate the model (see ASTM D5979 – 96 (2002). Standard Guide for Conceptualization and Characterization of Ground-Water Systems.	Not using industry standards limits the reliability of models developed. Uncertainty in model predictions within the LCNCA is already high for various reasons - but at a minimum, accepted industry standards should be clearly defined for all tasks to confirm overall credibility and acceptability of the resulting model and its results. This is a high profile case - yet standards are hard to find.	Strongly recommend that authors go back and redo any/all modeling which was not performed by industry standards. Many ASTM modeling-related standards have been around for decades now and are typically referenced in mining models I've reviewed.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
8	Model Code Selection	Approach/Basis	Tetra Tech, 2010a	Code selection was not really done. Inadequate code used for stated objectives.	This has very several very important implications to a) modeling LCNCA hydrology correctly, and b) translating effects of mine dewatering correctly beneath LCNCA and estimating realistic impacts. Authors failed to assess all important processes and needs to meet objectives, especially simulating important stream-aquifer dynamics and ET within LCNCA realistically. These are critical processes, but the groundwater modeling code (Modflow Surfact) models ONLY groundwater, and requires specification of external boundary conditions like Recharge, which must be estimated externally or just guessed. In addition, the authors note right after stating objectives (page____) that their code can't model required resolution in LCNCA and therefore will produce inaccurate/uncertain results. Additionally - many updated modules exist for Modflow - yet they failed to utilize or even review/consider (i.e., riparian ET module, or more advanced stream packages - i.e., STR2). Especially surprising is no effort made to utilize FE modeling tools (i.e. feflow), which could have provided high resolution gridding of critical streams/springs.	Go back and update model with more robust inputs and utilize more robust tools/gridding techniques so that critical features of interest in objectives (i.e., Cienega Creek and springs) can be modeled more appropriately. See http://www.astm.org/Standards/D6170.htm for appropriate standards to select an appropriate code. http://www.epa.gov/sites/production/files/2015-05/documents/402-r-94-012.pdf. See Anderson and Woessner 2015, "Applied Groundwater Modeling: Simulation of Flow and Advective Transport" Using mining industry standard code, FEFLOW would have permitted high resolution in 'regional' model to avoid this pitfall of suggesting the model right from the start can't model what the modeling objectives say the model should do (i.e., impacts to Cienega, Gardner etc.). FEFLOW FE code permits higher grid resolutions in key locations w/out excessive numerical code computational overheads, which the authors here suggest so limit the Finite Difference-based model resolutions that accuracy of simulating Cienega Creek is greatly diminished.
9	Model Extent		Tetra Tech, 2010b	Like other reviewers, the extent of the model is always much better defined along groundwater divides, and far enough away from internal model calculations that the boundary won't unnecessarily influence or dominate them. Although the western boundary doesn't play a big role in the calibration, during the model predictions, the dewatering extent clearly intercepts the western boundary, which is typically not a good thing to prescribe (or in this case 'over-prescribe').	Predictions of future impacts within LCNCA are unnecessarily influenced by an extent that isn't far enough away from internal changes in the model.	With a finite element code, it would be easy to add coarse model grid cells surrounding the existing extent to ensure any lateral boundary condition was far enough away from internal calculations of interest. Why introduce more uncertainty into the already uncertain model results?
10	Discretization	Horizontal	M&A 2010 and Tetra Tech, 2010b	The major concern here is that although the finite difference Modflow grid is refined around the mine pit, no effort was made to refine the grid around key water resource features, for example in the LCNCA. Instead, the authors point out how the coarse model grid doesn't permit accurate simulation (or calibration) of surface water features, for example within the LCNCA. See code selection comment I make later - if a finite element code had been selected, the resolution could have been high for both pit and stream areas without causing unnecessary computational overhead. As a result - the selected horizontal grid is inappropriate to meet stated objectives. There was no need to proceed with modeling.	Neither key features within the LCNCA (i.e., Cienega Creek), nor subsurface groundwater flow conditions beneath the LCNCA can be modeled with much accuracy. It is not clear why the modelers then proceeded to continue using the model to predict very low impacts (to 3 significant digits - see 6-4).	Modelers should consider using the correct modeling tool - i.e., Feflow is widely used within the mining industry, precisely because it handles very complicated geometries without sacrificing computational overheads. It is very similar to Modflow-Surfact, except it uses finite elements, which are much more flexible than the orthogonal constraints of a Modflow grid. In addition, Feflow also allows very flexible/simple definition of faulting (or thin dykes), allowing flow along them, or through them.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
11	Discretization	Vertical	Tetra Tech, 2010b	It is unclear why the hydrogeologic framework model vertical layering was defined at 200 feet, while the Modflow model was defined at 150 feet. The concern here is that hydrogeologic unit contacts/isopachs are not accurately reproduced within the Modflow model.	The potential impact could change how mine dewatering is translated from the mine pit into the LCNCA area, thereby introducing more uncertainty into the model predictions.	Confirm the influence of vertical model layering doesn't produce different model predictions if it were to actually match the hydrogeologic framework model layer thickness.
12	Boundary Conditions	Western Boundary	Tetra Tech, 2010b	Though modelers evaluated sensitivity of changing the western boundary to a no-flow condition, and to a GHB, Figure 3 in my review indicates that the no-flow condition would produce the largest impacts within LCNCA. My concern here is whether adequate attempts were made to re-calibrate the model assuming this condition.	Given the Steady State non-unique solution one obtains because of recharge-K correlation and effective calibration to just groundwater levels - I would be surprised if an equivalently valid calibration couldn't be obtained with a no-flow western boundary. Recharge and hydraulic conductivities appear to be loosely constrained in calibration. Finally, I wonder if other factors controlling 'conservatively' high impacts (see Figure 3) in LCNCA were adjusted in addition to a no-flow western boundary - would this model produce greater impacts within LCNCA?	Modelers should develop alternative conceptualizations where different model boundary conditions are combined with other model inputs (K values, recharge) and if these models can produce equivalent calibrations (though no calibration target levels were defined, based on needed calibration 'tolerance' in key areas like LCNCA) as the single one we already know is highly uncertain - then a better range of possible LCNCA impacts due to mine dewatering could be determined
13	Boundary Conditions	Northern Boundary				
14	Boundary Conditions	Southern Boundary	Tetra Tech, 2010a	No-flow boundaries assigned to southern/eastern boundaries, just because a surface-water (or GW) divide is assumed to occur here doesn't make sense. With enough drawdown from the mine propagating to these areas, GW can still cross these boundaries. As a result, the no-flow boundaries to the south are in fact 'conservative' an would over-predict impacts to CCCA versus propagating drawdown to the south of no-flow boundaries.		
15		Bottom Boundary	Tetra Tech, 2010a, Page 4.	"*The elevation for the bottom of the model is sufficiently below the anticipated bottom of the pit so that hydraulic stresses should not encounter the bottom model boundary during Open Pit dewatering or refilling* ." The concern here is whether any basis actually exists to justify this assumption, and what impact this has on predicted impacts at LCNCA. The way it is stated here implies this is just a guess and was never rigorously evaluated or justified. Although the bottom depth was extended from that specified in the M&A 2010 model, less data is available across the model domain at these depths to justify the increased depth. Page 3 in Tetra Tech, 2010 confirms this "*Two (2) additional horizontal slices were created at elevations of 2,000 and 1,600 feet amsl. These slices were constructed to be conceptually consistent with the existing 2,400 feet amsl layer by continuing previous trends to a depth of 1,000 feet amsl. However, there are no vertical boreholes at these depths to verify the interpolated geology* ."	I created Figure 2 for this review to indicate that a shallower 'no-flow' bottom boundary actually increases (conservatively) dewatering impacts within the LCNCA because lateral translation of pit dewatering drawdowns, like pumping from a partially-penetrating well, increases with greater penetration into aquifer (which in this case represents the specified no-flow bottom boundary).	Redo the sensitivity analysis, and adjust the bottom boundary by itself and with other sensitive parameters to get a better sense of how sensitive LCNCA hydrologic change is to the adjustment. This would provide information on how sensitive the bottom boundary is compared other parameters, which could then incorporated into a predictive uncertainty analysis - which could give a better idea of how uncertain LCNCA impacts are to uncertainty in the bottom boundary. Ultimately - this boundary could be off many hundreds of feet.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
16	Boundary Conditions	Rivers	Tetra Tech, 2010a	Fig 8, TT 2010 report simulates river discharge only in presumed long-term perennial sections. This fails to account for important redistribution of recharge from downstream routing and subsequent recharge along the many miles of ephemeral streams within the model area. Although, the ephemeral runoff may only occur during the wet season, effects of the focused stream recharge can last much longer once it increases saturated zone storage. Omitting this can reduce groundwater simulated levels beneath both perennial and ephemeral streams on an annual basis. As a result, impacts of dewatering at Rosemont would not be fully assessed.		Recommend using a fully integrated, physically-based flow model that simulates the strong coupling of flows between groundwater, unsaturated zone, overland flow and stream flow. Codes like MIKESHE would simulate evapotranspiration more realistically in both riparian and non-riparian areas.
17	Boundary Conditions	Rivers	Tetra Tech, 2010a	Fig 8 and Page 8, TT 2010. Its unclear why river cells were assigned only to presumed perennial stream segments, instead of assigning them to the entire ephemeral/perennial system and stream elevations used to specify where perennial conditions might exist. This is actually more 'industry standard' and doesn't FORCE the baseflow only in presumed perennial areas. Assigning cells in all stream segments would have allowed the modelers to better calibrate the model. In model areas where simulated levels are too high (i.e. above riverbed), the model would have predicted positive SS baseflows. If in known ephemeral areas, this negative feedback on calibration could have been used to make more appropriate adjustments to parameters or boundary conditions, likely improving calibration in critical areas.		Strongly recommend re-assigning river cells to entire stream networks (as defined in NHD datasets), setting appropriate stream depths only in 'perennial' areas based on accurate/long-term time-averaged data. Then calibrate the model, allowing it to determine on its own and based on other parameters to produce baseflow in the correct areas. The way it was specified in this model incorrectly masks impacts of poor calibration performance in riparian areas, especially along ephemeral streams. For example, Figure 39 shows significant over-simulation of heads along much of Cienega Creek/Gardner, which would have produced baseflow in the model, where it likely doesn't occur or is undesired, yet the model didn't permit discharge just very high overshot heads.
18	Boundary Conditions	Rivers		The basis for defining riverbed conductance (or leakance) could not be found. This combined with low weighting of baseflow/spring heads reduces calibration in these critical areas by design.	Impacts to baseflow (and streamflow) could be significantly affected. The substantial calibration error beneath much of the Cienega Creek (tens to hundreds of feet of over/under-predicted levels) wasn't included in the analysis or predictions.	Strongly recommend conducting stream-aquifer studies along key ephemeral/perennial reaches/tributaries of Cienega Creek to determine effective conductance values by reach. This will greatly improve the ability to translate changes in head beneath streams and changes in surface water hydrodynamics throughout the year.
19	Boundary Conditions	Rivers		River stages apparently specified within the model were never reported. The basis or what was specified can't be reviewed.	Using the wrong stage for long-term SS runs could strongly affect long-term impacts.	Use the right code, be transparent, stage could have been sensitivity parameter.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
20	Boundary Conditions	Well Pumping	Tetra Tech, 2010b	Historical (loosely guessed at 300 to 1500 gpm page 20) and future effects of surrounding pumping within the model domain was not included in the assessment of impacts at LCNCA. This makes little sense. The concern here is that proposed mine dewatering (400 to 500 gpm Tetra Tech, 2010b and 600 gpm M&A, 2010) will only add to the cumulative effects of surrounding users and reductions in recharge and increases in evapotranspiration from changing climate. The fact that historical pumping in the basin is likely much greater than predicted pit inflows makes the decision to not consider surrounding pumping unrealistic.	The extent and magnitude of predicted impacts due to mining on LCNCA water resources is incorrect, because the model wasn't calibrated to significant surrounding historical groundwater pumping, which introduces error into the model calibration, but also because it doesn't consider continued future, likely growing, impacts of surrounding groundwater use.	The model should be re-calibrated to include surrounding pumping, even if approximate levels are considered. This will complicate model calibration, but this stress is very likely as great or much greater than predicted mine dewatering rates, which the authors have already shown significantly alter 'background' groundwater levels and streamflow. At a minimum, sensitivity of model predicted impacts within LCNCA should have evaluated the effects of likely continued pumping and even increases as is standard practice for municipal water supply studies.
21	Boundary Conditions	Recharge	Tetra Tech, 2010a	Figure 6 indicates higher recharge west of Cienega. Coincidently, this seems to be highest over pit area, and decreases away from the pit. The problem is that higher recharge reduces lateral drawdown extent and magnitude from pit. Impacts at Cienega Creek could be much higher. The recharge rate (5.4% of annual precipitation) seems very high compared to other basins in arid/semi-arid areas. This also suggests that recharge has been over-specified, which would require adjustments to calibrated hydraulic properties to compensate.	Less impacts would be predicted at LCNCA than if recharge wasn't so high between mine and Cienega Creek.	Assess different spatial configurations of recharge (i.e., try more uniform values) in calibrating model. It is highly likely that the 'calibrated' TT model is very non-unique and much different parameter/BC configurations could also yield 'acceptable' calibration. Evaluate lower recharge values between mine and Cienega Creek.
22	Boundary Conditions	Recharge	Tetra Tech, 2010a	Figure 6 also shows no increase in recharge in ephemeral reaches due to focused runoff from higher elevations, which a fully integrated hydrologic/hydraulic model would easily show.	The net effect of omitting this focused stream recharge would be incorrect simulation of stream-aquifer interaction (i.e., baseflow discharges) in downstream perennial sections, incorrect simulation of heads near both ephemeral and perennial reaches of the important surface drainages (i.e., Cienega Creek), increased calibration errors, and most importantly, unreliable estimates of future impacts of mine dewatering on hydrologic response in LCNCA.	Recommend significant revision of distributed recharge estimates and using a well-documented method (i.e., USGS Basin Characterization Method). Ideally, I would recommend using a fully integrated, physically-based flow model that simulates the strong coupling of flows between groundwater, unsaturated zone, overland flow and stream flow. Codes like MIKESHE, USGS GSFLOW, Hydrogeosphere etc. would all simulate storm runoff, distributed and dynamic recharge and stream-aquifer dynamics much more realistically than forcing a groundwater model to this.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
23	Boundary Conditions	Recharge	Tetra Tech, 2010a	Despite considering more factors than the M&A (2009) model, there appears to be no published basis for the estimation of distributed recharge in the model. Attempting to determine time-averaged spatially distributed recharge without considering such critical factors as a) rainfall intensity/duration, b) unsaturated zone flow including capillarity effects, and c) hydrodynamic overland and stream flows, is simply wrong and will produce substantial errors, which then translate to incorrect parameterization in other model parameters (i.e., hydraulic conductivity). Many fully integrated, physically-based modeling codes exist which simulate coupling of surface flow hydrodynamics with unsaturated and saturated zone processes (i.e., GSFLOW, MIKE SHE/MIKE11, Hydrogeosphere, HSPF etc. etc.). Any of these could have been used to produce external time-averaged recharge events using actual climate data (see Jyrkama and Sykes, 2006). It is well documented that non-unique solutions to calibration will result when using highly correlated parameters like hydraulic conductivity and recharge in a steady state solution. Introducing other calibration data (i.e., baseflows which are not weighted really low, water quality data, temperature, etc.) can help reduce the non-uniqueness in solution.	The implication to estimates of impacts at LCNCA is that modeled results can be considered non-unique, because of the approach used to calibrate the steady state model. This means estimates of flow conditions for pre-mining and during/post-mining are uncertain and therefore, not very reliable. Despite the authors showing that their model is calibrated using optimal parameters, no physically-based methodology was used to externally define the recharge distribution (markedly different than the M&A modeling) and because calibration weighted baseflow and spring data very low relative to groundwater well data - the solution is most likely non-unique, meaning that much different recharge and hydraulic property configurations could have been specified and resulted in the same model calibration. Where this matters is when future predictions are made, well outside of calibrated conditions, notable differences in results or impacts would likely occur given the different configurations of key inputs like recharge and hydraulic conductivity. In effect, this only increases the uncertainty of estimates of mine dewatering impacts within LCNCA, which could be much higher than indicated.	It is strongly recommended that Rosemont consultants utilize more advanced modeling tools that have been around for decades (i.e., physically-based, fully integrated modeling tools like MIKE SHE/MIKE11, GSFLOW, Hydrogeosphere etc.) to estimate much more realistic/qualified spatial distributions of recharge, determined from available long-term, climate-driven events and using available soils, vegetation, stream morphology etc.). This by itself would reduce much of the solution non-uniqueness. I showed how this can be done in my dissertation work in 2002 in the Black Mesa area in northeastern Arizona, following similar concerns about validity of recharge estimates in a regional Modflow model there. Even if a physically-based, fully integrated code is not used to estimate recharge, a more sophisticated recharge estimate should be determined. For example, the USGS developed a water balance model (BCM – Basin Characterization Model) that has been applied in a variety of basins to calculate more realistic spatially/temporally variable recharge. It calculates the recharge based on data available within the groundwater model area (see http://pubs.usgs.gov/sir/2010/5193/PDF/GreatBasinAppendix03.pdf, or http://acwi.gov/swrr/p&p_library/dec6-2011_uc/SWRRM_HANSONetal_120911.pdf).
24	Boundary Conditions	Evapotranspiration (ET)	Tetra Tech, 2010a	Specification of ET in only a limited number of presumed ET-cells along perennial streams (i.e., Cienega Creek) likely significantly under-predicts total evapotranspiration from the model. Review of specified ET-cells (Figure 7) indicates too few cells were specified, especially in critical area of LCNCA. For example on the largest western tributary into Cienega Creek, north of Gardner Canyon, lower Gardner Canyon etc., where landfire vegetation datasets, or even google earth clearly show existence of riparian vegetation. Lastly, the M&A, August 2010 modeling report indicates that extinction depths were varied by vegetation types in the different ET zones, but Tetra Tech only specified a uniform depth (16.4 ft.), due to lack of data. This depth is greater than most zones specified in the M&A model.	Under-specifying the number of ET-cells, results in an under-prediction of localized ET loss, which results in higher heads in these critical locations and likely results in unnecessary reductions in riverbed leakance values to compensate. Calibration in the LCNCA is therefore incorrect and increased and unaccounted for uncertainty in predictions. Over-specifying the depth of extinction depths would unnecessarily remove groundwater at depth than might otherwise be available for discharge into perennial reaches, along Cienega Creek. This would again lead to incorrect adjustment of calibration parameters like streambed leakance rather than extinction depths (not calibration parameters).	Highly recommend specifying ET in all cells. Let the model determine where ET occurs and at what rates. If it is clearly too high in areas it shouldn't be (i.e., where vegetation is largely absent) then other parameters/BC in the model need to be adjusted. The modeling conducted here doesn't appear to have utilized this useful approach during calibration, but should. Specify more appropriate extinction depths based on plant types.
25	Structural Features	Structure	M&A 2009	Fig 4 sections in M&A, 2009 report indicate many uncertainties in geologic features, including: a) faults, b) depths/configuration (i.e., see many dashed lines with question marks. These can lead to substantial structural/conceptual model uncertainties.	A secondary concern is that negative feedback is not provided during calibration to help guide calibration, for example when simulated levels exceed the ground surface outside of specified ET-cell locations, calibration is not necessarily informed	Assess full range of drawdown impacts due to range of possible geologic feature uncertainties.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
26	Structural Features	Bedrock Depth	Tetra Tech, 2010b	Effects of uncertain bedrock depth on LCNCA water resources not assessed.	Results in increased uncertainty in predicted impacts from mine dewatering on LCNCA water resources.	Assess full range of drawdown impacts due to range of possible bedrock depths/configuration.
27	Hydraulic Properties	Hydraulic Conductivity - Horizontal	M&A 2010	Hydraulic test data reported on Figure 29 in M&A 2010, particularly those in LCNCA vicinity (i.e., Anamax test wells) appear higher (up to an order of magnitude) than calibrated values reported for each unit in TetraTech, 2010b model (Figures 18 through 33). It is surprising that these data were not used during automatic calibration with PEST as pilot points. The concern here is that departure of calibrated model from actual field data, albeit it sparse, combined with poor calibration in the LCNCA area, strongly suggest other model inputs are probably incorrectly specified, for example spatial distribution and magnitudes of recharge.	The calibrated model error is unnecessarily increased, resulting in increased uncertainty in modeled future impacts of mine dewatering on water resources within the LNCNA.	The Tetra Tech 2010a model should be recalibrated using these field data values as pilot points, so that the calibrated model honors these important data constraints on the model calibration.
28	Hydraulic Properties	Unconfined Storage		The assumption of unconfined conditions within the aquifer system limits the translation of dewatering at the pit (see Figure 3), compared to an assumption that dewatering may translate further and with greater impacts via confined flow within karstic/limestone units.		Demonstrate magnitude of impacts within LCNCA using confined conditions in lower units (i.e., KSD).
29	Model Calibration		Tetra Tech, 2010	Alternative conceptual models. None were produced, which is surprising given the high level of uncertainty associated with data quality/quantity, characterizations and conceptual flow. This is typically where most uncertainty is introduced into model predictions.		See Neuman and Weiranga, 2003 NRC guidelines.
30	Model Calibration	Calibration Targets	M&A 2010, Tetra Tech, 2010a, Tetra Tech, 2010b	Fig 28 in M&A, 2010 shows many GW well locations with single water level measurements for a single year, with some years missing. Yet, checking data against UGSS NWIS dataset - many are decades old, likely inconsistent with current levels and don't represent the true seasonal variation as noted on page ___ in Tetra Tech, 2010b "*The water-level and stream flow fluctuations observed in the available data likely underestimate actual fluctuations.* ". What is the error and implication to calibration in LCNCA? The quality of calibration and reliability of subsequent predictions depends heavily on these groundwater levels - not even a simple temporal analysis appears to have been performed to qualify the data (i.e., are measurement dates reasonable, seasonally-biased measurements (i.e., time-average measurements don't capture true range) or whether measurements are impacted by pumping weren't considered, thereby introducing significant error into the calibration, just from data collection. GW levels are known to vary significantly at wells in the system.	Using biased, unqualified well data without more rigorous analysis, or considering adding qualified wells, only adds to the total calibration error, as the modelers are forcing a model to reproduce likely biased data. The M&A report indicates levels can fluctuate at least 30 feet in some wells, which raises serious concerns about the ability for the model to accurately/realistically simulate flows within LCNCA during pre-mining, and to estimate changes following mine dewatering.	Recommend making at least monthly measurements in all wells shown and using time-average. In addition, it is essential that these well measurements be classified into depth zones and calibration statistics provided for each zone, showing potential bias - standard industry practice.
31	Model Calibration	Calibration Target Weights	Tetra Tech, 2010a	Each calibration data point was assigned weights that discount critical LCNCA water features.		

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
32	Model Calibration	Calibration Targets		Calibration constraints other than groundwater well data do not appear to have been considered. For example, why weren't vertical and/or horizontal gradients used in addition to heads at wells? Were well pairs screened across the different aquifer zones unavailable - and if so, why were these data collected to improve calibration? Why weren't limitations on heads (i.e., apparently simulated above ground surface in many non-stream areas) included as additional calibration constraints (see simulated groundwater depths - Figure 4 in my review).	LCNCA flow conditions not correctly simulated.	The models should be re-calibrated, constraining groundwater levels by some depth below ground surface (i.e., based on vegetation distributions, which would otherwise thrive if groundwater were a shallow as it is in riparian corridors). An advantage of using fully integrated, physically-based codes like MIKESHE/MIKE11 is that these codes automatically convert ponded water (which would occur when groundwater levels exceed ground surface) to surface runoff. If this occurred as it does in the Tetra Tech model, it could be corrected by adjusting appropriate parameters, or reconceptualizing.
33	Model Calibration	Calibration Locations/Density	TetraTech, 2010a	Spatial density and number of wells appears reasonable within the model domain (i.e., Fig 6-25), though still spatially biased in LCNCA. However, it is unclear how wells are distributed by depth and formation (i.e., consistent with formations shown in sections shown on Figs 4-3 and 4-4 of same report).	Uncertainty is increased in model predictions within the LCNCA, if water levels aren't clearly defined within specific units.	Recommend preparing maps of all wells screened by depth and hydrogeologic formation, noting those which are open to multiple formations and those which only partially penetrate given formations. It would also be worth noting which wells are currently production wells (or influenced by nearby production wells), from which measurements were taken (which are likely biased towards the low side).
34	Model Calibration	Quality of Calibration data		The adequacy and errors of calibration data is never really evaluated for meeting objectives. No effort is made to identify potential errors from all model inputs, and how they translate into model calibration, and then into model prediction uncertainty.		Authors should conduct a thorough assessment of all data used for model input and calibration, and then evaluate implications for model predictions.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
35	Model Calibration	General Calibration (heads)	TetraTech, 2010b	Fig 6-25 and 6-26 indicate very high local head residuals along Cienega Creek (for highly subjective 'weighted' case, residuals indicate bias, or over-estimated heads, up to 49 feet in the mid-/lower-perennial reach, while in upstream in Gardner Canyon, residuals are biased towards under-predicting heads near stream by up to 50 feet). This is a very large range in a critical area that requires much higher levels of calibration to ensure that a) flow magnitudes and directions into/out of these important LCNCA surface water features are even remotely correct. In addition, in Figure 6-29 simulated contours appear overly-dominated by Cienega Creek river boundary conditions in lower perennial reach (and in Gardner, the opposite occurs, because no river cells are specified), compared to manually contoured from data, strongly suggesting hydraulic property variations are not captured well in the model, or riverbed conductance values are set too high. Of course, this doesn't incorporate the acknowledgement by the authors that the target calibration well water levels don't likely reflect true seasonal range, adding to the calibration error.		Recommend recalibrating the model to better capture the shape of the contours around major surface drainages like Cienega Creek, to better capture flow conditions. Also recommend calibrating to transient conditions ad considering a fully integrated hydraulic/hydrologic model to simulate the coupled surface water-groundwater system more rigorously/realistically.
36	Model Calibration	General Calibration (heads)	TetraTech, 2010b, M&A 2010	In Figure 6-29 simulated contours appear overly-dominated by Cienega Creek river boundary conditions in lower perennial reach (and in Gardner, the opposite occurs, because no river cells are specified), compared to manually contoured from data, strongly suggesting hydraulic property variations are not captured well in the model, or riverbed conductance values are set too high. Of course, this doesn't incorporate the acknowledgement by the authors that the target calibration well water levels don't likely reflect true seasonal range, adding to the calibration error. Interestingly, groundwater contours in M&A 2010, Figure 26 seem to show observed detail especially along key water drainages (i.e., near wells 14aaa, 16cbb, 18ddb, along alluvial deposits) apparently lacking in the TetraTech contouring shown on Figure 6-29. This appears to be a critical oversight in Tetra Tech model.		Recommend recalibrating the model to better capture the shape of the contours around major surface drainages like Cienega Creek, to better capture flow conditions. Also recommend calibrating to transient conditions ad considering a fully integrated hydraulic/hydrologic model to simulate the coupled surface water-groundwater system more rigorously/realistically.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
37	Model Calibration	Calibration Statistics	Tetra Tech, 2010b, Page 62	"*For example, the residual standard deviation divided by the range of observations is considered acceptable if it is below ten (10) percent (Anderson and Woessner, 1992). For the steady-state model, this value was below five (5) percent for both unweighted and weighted residuals.* " The concern here is that this often-cited metric of 'acceptable' calibration doesn't reflect the poor calibration in the local LCNCA vicinity, nor does it reflect the very low weighting assigned to stream gage data or zero weighting of 67 springs within the model area - which leads to a non-unique SS solution. More importantly, calibration target values were never established for the LCNCA which would should have driven calibration in this area so that the predictive modeling could have actually yielded realistic and reliable estimates of impacts to water resources in the LCNCA - a key modeling objective.	Lack of calibration to critical water surface features within LCNCA has reduced the overall credibility and accuracy of the calibrated model to produce meaningful/reliable estimates of mine dewatering impacts within the LCNCA or its surface water features.	Collect basic stream and spring stage/discharge data throughout LCNCA and surrounding area. This should have been done during the characterization and conceptualization phase. Re-calibrate the model and use the highest weighting in these areas, to force the model to simulate conditions in the LCNCA at the highest level possible - at a level which can then be used to better assess a more realistic range of impacts to the water resources within this area. I've made other suggestions, such as using more advanced modeling tools to better handle the resolution and physical processes, which should also be considered.
38	Model Calibration	Transient Calibration	TetraTech, 2010b, (M&A, 2010)	No transient calibration appears to have been performed, so storage values can't be determined and more importantly, transient predictions of magnitudes/extent of drawdown and streamflow reductions can't be determined reliably. Worse, available groundwater levels in time, for example on Figure 28 (M&A, 2010) simply don't appear to be anywhere near adequate for developing annual time-series that reflect actual annual highs and lows year to year located throughout the model and within the major hydrostratigraphic zones. The problem with this is that this prevents calibration of a transient model, but more importantly diminishes the credibility and reliability of steady state calibration, which appears to time-average water levels in many wells (Figure 28), despite large seasonal variations (exceeding 30 feet), but only having single measurements from some years and apparently not considering effects of local pumping in the area.	Predicted future change in heads, ET, baseflows due to mine dewatering can't be determined in LNCNA with much accuracy.	Collect monthly groundwater levels of higher quality, at more useful locations to calibration (i.e., beneath stream, adjacent to stream, hill areas, near springs etc.) and calibrate the model parameters to transient pre-mining conditions to demonstrate model can perform under current conditions. This is critical, because under mine dewatering, the system will be perturbed well outside of pre-mining calibrated conditions, making predictions likely more dependent on highly uncertain features/configurations/assumptionsthat don't play as big a role in controlling flows under pre-mining conditions. Every opportunity to improve models to pre-mining conditions should be performed to increase confidence in the model under significant post-mining stresses. In fact, calibration to other data, such as geochemical or temperature, could also be done to further demonstrate confidence in the model calibration and future performance.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
39	Model Calibration	Baseflow Calibration	Page 8, Tetra Tech 2010a Page 55, TetraTech 2010b report	By design, TT2010 report, page 8, indicates only qualitative calibration of stream baseflow, in pre-determined areas would be done because of the 'regional-scale' of the model. This is really surprising as numerous other models over much larger areas weight such observation data very high, given the importance of simulated impacts to baseflows and strong influence such river boundary conditions have on simulation of these impacts. Page 55, TetraTech 2010b report states "Stream flows, in conjunction with water-level measurements, were used during model calibration to reduce the non-uniqueness of the model parameters. However, stream flows were not rigorously matched due to their low base-flow rates (< 1 cfs). Stream". Effectively, calibration was done to just water levels - as the three local flow points were weighted very low.	Sparse baseflow data combined with very poor calibration of these data by low weighting produces very unreliable (unqualified) estimates of flow conditions (pre-mining) and very uncertain estimates during/after mining.	Strongly recommend re-weighting all available streamflow observations. Strongly recommend using a fully integrated physically-based model, like MIKESHE/MIKE 11 to simulate the coupled GW-SW system without having to so significantly limit model performance, by design.
40	Model Calibration	Local Calibration Results		Calibration statistics for the LCNCA-specific area weren't provided. They appear poor relative to the entire model area, which is not great. This is inconsistent with the objective of the modeling, which was to look at specific impacts of key water resources in the area.	Credibility and accuracy of modeled calibration are essential to reporting reliable/believable short-/long-term predictions of impacts to LCNCA water resources due to mine dewatering. The calibration data look poor, hence the reliability of estimates is poor in the LCNCA.	Strongly recommend conducting an evaluation along key drainages of CCCA, not just main branch, to evaluate vertical gradients/baseflows/temperatures in streams. This would greatly reduce the uncertainty in change in discharge as a function of head decline.
41	Sensitivity Analyses	Calibration	Tetra Tech, 2010b	Sensitivity analysis – no references on which methodology is used. ASTM D5611-94, 2002. (Standard Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application, American Society of Testing Materials) summarizes methods used in standard sensitivity analyses? In particular, Figure 5 in ASTM D5611-94 suggests evaluating 4 different types of sensitivity after conducting calibration and prediction sensitivities. Had the modelers conducted an analysis according to this standard, they could have determined where more data is required (i.e., Sensitivity type IV indicates model calibration doesn't change to parameter change, but model conclusions do). It is likely the non-unique SteadyState solution due to calibration effectively against just heads and varying correlated parameters like K and recharge would show type IV sensitivities).	Implication is that results of the sensitivity analysis were not used to identify data deficiencies - apparently it was only to attempt to demonstrate very low impacts occur in LCNCA water resources, when somewhat biased selection of parameters are adjusted, somewhat arbitrary amounts, individually (as opposed to varying more impactful combinations of parameters or distributions) for a model which was pre-determined to not be able to predict critical stream-aquifer flows due to grid resolution coarseness, which was due to selecting a code incapable of simulating required flow conditions to meet objectives.	It is recommended that the sensitivity analyses be conducted based on industry standards, and used to identify all key parameters (or distributions) and boundary conditions that might affect (i.e., see Figure 3) LCNCA flows. The focus should then be on conducting a more rigorous/robust uncertainty analysis so that a more realistic and comprehensive range of uncertainty in predicted impacts within LCNCA can be produced.

No.	Model Step	Model SubStep	Report	Concern	Implication for Prediction at LCNCA	Recommendation
42	Sensitivity Analyses	Predictive		The selected parameters and range of adjustments were highly biased and do NOT consider a) all factors that influence mine impacts within LCNCA, or b) consider combinations of key factors that would increase resulting impacts. Figure 2 in this review shows a more complete set of factors I believe should have been evaluated in the sensitivity analysis that would have conveyed a more realistic, conservatively larger impact within LCNCA due to mine dewatering. In addition, important parameters like recharge and hydraulic conductivities are spatially distributed, but no effort was made to evaluate the sensitivity of different spatial distributions on water resource impacts in the LCNCA. This is surprising, given the significant differences between the M&A and TetraTech model recharge distributions and magnitudes. It appears the authors may be confusing a sensitivity analysis with uncertainty analysis. The two are very distinct, the latter of which (as EPA proposed) provides much better estimation of uncertainty, albeit it just for parameters and not all uncertainty sources (i.e., including conceptual, data etc.).	The reported small impacts at LCNCA due to the biased adjustment of 'cherry-picked' parameters masks the very likely broader range of impacts that would have been simulated had the modelers considered: a) adjusting combinations of sensitive parameters, and b) consider adjustments that evaluated spatial distributions of sensitive parameters like recharge, which I believe was also incorrectly specified (i.e., no focused streambed recharge), likely too high etc. - all of which would have effectively dampened the mine dewatering impacts within LCNCA (as I indicate on Figure 2).	Recommend conducting a less biased, more comprehensive predictive sensitivity analysis that considers all parameters and boundary conditions that potentially impact LCNCA. The results of this should be to identify those parameters which the LCNCA response is most sensitive to (not just the entire model). And then these more sensitive parameters should feed into a more rigorous uncertainty analysis, along the lines of what EPA already proposed, where combinations of sensitive parameters (and their distributions). The uncertainty analysis address the main issue with conducting a sensitivity analysis as presented by Rosemont consultants, where the adjustments very likely perturb the model well out of calibration, which in effect invalidates the model results. Uncertainty analyses, like Monte Carlo, GLUE etc. must adjust parameters, combinations of parameters (and even spatial distributions of parameter values) such that each realization must produce results which remain equally calibrated as the 'calibrated' model. Even parameter uncertainty analyses don't capture the full uncertainty of predictions, much of which typically occurs due to conceptual model (i.e. structural) uncertainty, which strongly argues for developing multiple conceptual models until they can be dismissed. The modeling conducted here didn't follow this approach, though many in the modeling community actually do so.
43	Predictions			Once built, the pit will be a constant sink, drawing in surrounding groundwater in perpetuity	Once mining ceases and dewatering impacts occur in LCNCA, no amount of monitoring would mitigate the future passive ET sink at the pit. It would be difficult at best to mitigate impacts at LCNCA, especially given the likely loss of funds.	At a minimum, conduct simulations now to show where monitoring locations would be placed (i.e., close to the mine), which would confirm future modeling predicted dewatering magnitudes/extents
44	Uncertainty Analyses			Various sources of uncertainty/error in all inputs, assumptions, boundary conditions etc. are not estimated, discussed or implications on LCNCA impacts evaluated. Many estimates of flows/conditions are presented, but no sense of the accuracy or predictive uncertainty is provided. Standard modeling suggests it is inappropriate to present results without qualifying the outputs (Neuman and Wieranga, 2003). There are numerous USGS studies describe how uncertainty analyses are conducted (http://water.usgs.gov/nrp/proj.bib/hill.html),and other references here: http://people.sc.fsu.edu/~mye/pdf/paper15.pdf.	Not conducting a rigorous uncertainty analysis does not permit regulators or other reviewers to assess the full nature (i.e., magnitude and extent) of what could actually happen within LCNCA due to Rosemont mine dewatering. So, in effect, an informed decision can't be made until a better sense of the full range of uncertainty is estimated. The sensitivity analysis performed by the modelers, arbitrarily adjusting 'cherry-picked' parameters up/down, does not provide a realistic estimate of the full range of uncertainty in predicted changes to water resources in the LCNCA.	A rigorous uncertainty analysis is strongly recommended (not a calibration or prediction sensitivity analysis) so that a more appropriate, complete range predicted impacts on hydrology within the LCNCA can be assessed by regulators/reviewers.